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I, Po-Hung Chiu, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture.

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The Structure of L-System

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The Structure of L-System

MoMA PS1 Canopy Design

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by

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Abstract

With continued digital technology development, computer has not only been seen as only the assistant as the tool, but also could be a medium of design development. This project is a study of a methodology for the parametric design and fabrication of the bionic structure.

For centuries, architects have been inspired by natural forms and geometries. Their designs have been influenced by natural structures, proportions, colors, patterns and textures. In 1968, the biologist Aristid Lindenmayer proposed a string-rewriting algorithm which can model plants and their growth processes. Since then, Lindenmayer Systems or L-systems have evolved and found many practical applications in the computer visualization area, such as generation of fractal diagram, realistic modeling and high quality visualization of organic forms.

More recently, remarkable advances have been made in architecture in the field of modeling and visualization. Specifically, the integration of scripting languages into CAD applications enables direct visualization of objects generated using algorithmic processes. Therefore, L-system is ready to be a new tool for architects, and in the meantime architecture gain more opportunities to be designed with complex, organic or bionic ways by using parametric tools such as Rhino with Grasshopper. However, how can the L-system apply to architectural design process through parametric tools? How to make L-system adapt to an architectural site?

Keywords: L-system, parametric design, Rhino, Grasshopper

Preface

In late 2013, I traveled to Europe and visited many fancy and modern architecture. Building with strange, organic forms or with particular patterns always catch my attention. For example, Sagrada Família which was designed by Antoni Gaudi presents many natural or organic elements of geometries, and it began to build hundred years ago; Toyo Ito's Porta Fira Towers was designed with an organic form and random windows, and it was completed in 2010. I stayed in this hotel for one night.

Both projects were in Barcelona but in a different era. Antoni Gaudi was in the era without computer technologies. He still followed the natural rules to create the geometries but just lost some opportunities to deal with more possibilities. Even if his project looked so complicated, every element still appeared repetitively. For example, columns or windows were modular and symmetrical. On the other hand, Toyo Ito had the chance to use parametric tools to simulate every possibility of the building and compare with each result. The hotel tower was designed with an organic form and appeared to change as one moves around it. The façade was divided into two layers: The inner skin was a sealed envelope for meeting all acoustic, thermal and sealing requirements; the exterior façade acted as a second skin that provides texture and variable geometry.

However, many of bionic ideas are still difficult to put them into action today. In addition, most of existing cases are constructed by columns and exterior walls as the definition of the Primitive Hut by Marc-Antoine Laugier. In fact, every creature in the nature is not only consisted by linear grid. Their body structures sometimes exist in morphological changes, such as exoskeleton, shell, or honeycomb. Therefore, based on the parametric conditions and biology, the architecture is always not necessary to be a latticed framework system. But how does a building which is designed as an organic form be inspired by natural rules?

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1. INSTRUCTION

1.1 Background

Artificial life (A-Life) is a field of study and an associated art form which examine systems that are related to life, its processes, and its evolution, through the use of simulations with computer models, robotics, and biochemistry. ^[1] The discipline was named by Christopher Langton, an American computer scientist, in 1986. ^[2] A-Life imitates traditional biology by trying to recreate some aspects of biological phenomena. ^[3] It studies the logic of living systems in artificial environments in order to come to an understanding of the complex information processing that defines such systems. Most representative of artificial lives are: robotic insectoid, the game of life and other cellular automata, genetic algorithms, L-systems and simulations of ecosystems. ^[4] However, for computer-aided modeling, cellular automata, L-systems and genetic algorithms are used commonly in the architectural field because these A-Lives have more potential for the translating script into geometry for immediate virtualization.

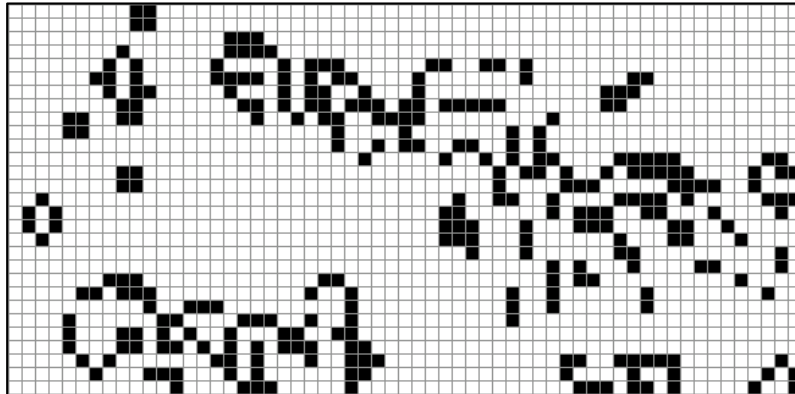


Figure 1.1 - The Game of life

The game takes place in a two-dimensional grid of infinite size consisting of individual square cells. Each cell is either alive or dead and the initial configuration uniquely defines all subsequent states. Obtaining one configuration from a previous one is determined by a set of rules, which include the 8 neighbors of each cell. ^[5]

Cellular automaton (CA) is a discrete model studied in computability theory, mathematics, physics, complexity science, theoretical biology and microstructure modeling.^[6] the Hungarian-born U.S. mathematician John von Neumann, one of the pioneers of computer science, had begun to explore the nature of very basic a-life formats called cellular automata in the 1950s. Cellular automata are imaginary mathematical "cells", analogous to checkerboard squares, that can be made to simulate physical processes by subjecting them to certain simple rules called algorithms.^[7] Researchers can use CA systems for planning or organizing spaces. It generates patterns, from organized 2-D patterns or 3D-cubes. Thus, architects might be able to suggest architectural strategies which differs from a traditional deterministic methods in that current results are the basis for the next set of results. This recursive replacement steps continues until some options could be achieved.



Figure 1.2 - Textile Cone
A cellular automaton pattern on the shell

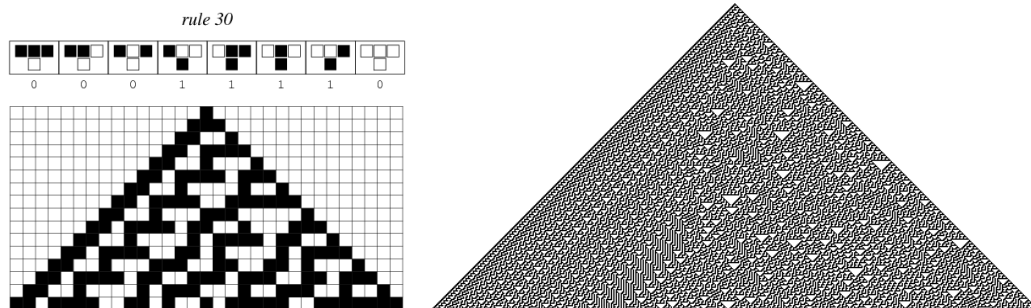


Figure 1.3 - Cellular Automaton Pattern: Rule 30

Another significant A-Life researcher was biologist Aristid Lindenmayer who was interested in the mathematics of plant growth that was found in the 1960s. Through the use of a few basic algorithms which is called Lindenmayer System (L-system) now, it could model biochemical processes as well as tracing the development of complex biological forms such as flowers. This algorithm can be used in assisting the generation and visualization of complex architectural form through JAVA applets or Rhino with Grasshopper.



Figure 1.4 – The biologist
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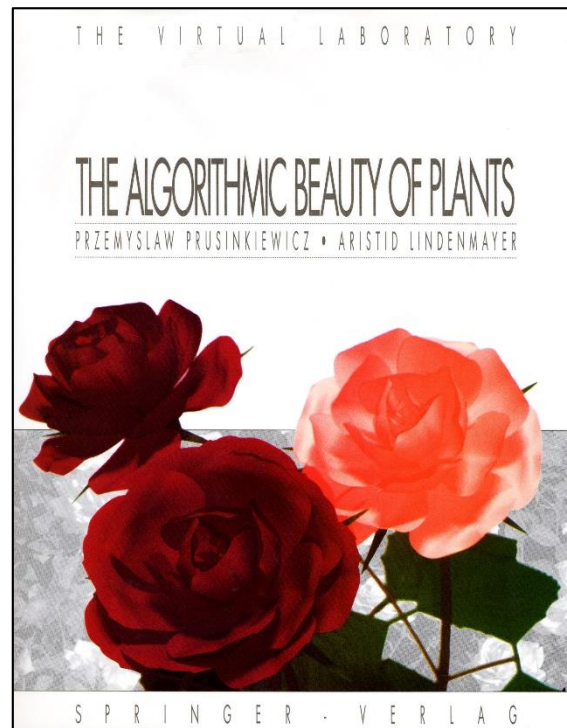


Figure 1.5 - The Algorithmic Beauty of Plants
This is a book by Przemysław Prusinkiewicz
and Aristid Lindenmayer

Genetic algorithms (GAs) in particular became popular through the work of John Holland in the early 1970s, especially his book *Adaptation in Natural and Artificial Systems*. His work originated with studies of cellular automata, which is conducted by Holland and his students at the University of Michigan. ^[8] Genetic Algorithms offer an effective solution to the problem by solving optimization and search problems, and operating on a population of possible solutions. In

architecture, GAs operate in two different ways: as optimization tools or as form-generation tools. As optimization tool, GAs address well-defined building problems, such as structural, mechanical, and thermal and lighting performance. As form-generation tools, GAs are used under the scope of the concept of Emergence. The dual operation of GAs in architecture will be analyzed hereafter. [9]



Figure 1.6 - Music Pavilion – Salzburg Biennale 2011

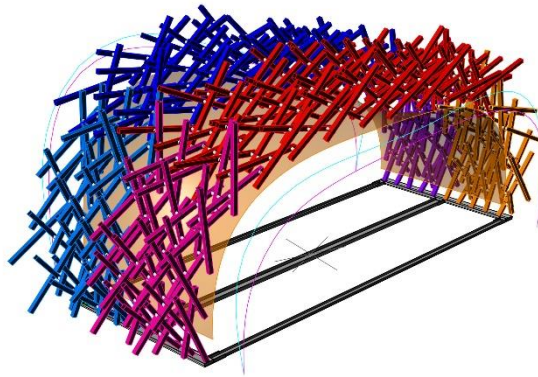


Figure 1.7 – The structural analysis of Pavilion

This is a project which used Grasshopper and Genetic algorithms to search a solution for the structural design

The foregoing A-Lifes (CA, L-system and Gas) are the algorithms which have been developed and exploded in the architectural field recently. Architects are able to use these tools to not only study their design idea but virtualize and optimize geometry, dimension, area and volume for finding the best solution.

1.2 Problem and Purpose

Few decades, the digital technology applied in the architectural field is everywhere, however, some bionic architectural ideas are still hard to implement the result in reality and remain on the paper architecture or the digital visual simulated model.

Until now, most of the projects of finished organic form are made by parametric tools such as Rhino with grasshopper or Revit with Dynamo, and some process are still leaving the technical parts to contractors and let engineers deal with that the organic form. However, if architects try to look for some algorithms to simulate organic form in their projects and expecting to program by themselves, they will generally face difficult programming language and spend a long time on learning it from the beginning for achieving the ultimate goal.

Therefore, programming language needs to be simple enough for architects, who do not hold computer science background, to learn. Compare with three A-Lives that are just mentioned (cellular automata, L-systems and genetic algorithms), L-system would be the best candidate for this scenario.

Here are several reasons for architects to use L-system for their projects.

1. "With L-system architects can easily experiment and visualize a very unique and exciting array of form and shapes that can be further manipulated with CAD.
2. L-system can assist in visualizing how forms are derived and transformed.
3. L-system can generate 2 and 3-D geometries in a matter of seconds that otherwise would take countless hours to generate using traditional CAD approaches.
4. Many of those forms would be practically impossible to generate without

such assistance.

5. L-system can be used to apply organic growth principles to architectural design.
6. A design can begin with a very simple set of rules and then experiment with countless forms, variations and transformations, all with very quick and simple changes in the axiom writing."^[10]

Based on the parametric environments and biology, L-system will propose an experiment of organic structure which would be constructed without traditional, latticed framework, enabling the structure to create by means of natural creature or organic elements. It then could be optimized through the computer program with not only inspiring from the natural system that has evolved efficiently, but also adjusting to several environmental factors such as solar, wind, acoustics or temperature.

The idea will be practiced via a competition which is held by MoMA PS1 every year, to be presented on how it works in the realistic environment, and be used on the 3D printer or 2D cutting machine to fabricate a mock-up to examine the possibility. As a result of this bionic design, the designers who deal with the organic structure project will have a set of design flow for making bionic structure more systematically and methodically for their clients.

1.3 Methodology

Because there are not many successful cases using L-system nor does it have the design flow for reference, this research that is based on the parametric tool and L-system will propose a set of methodology for designer who consider to use L-system for their design process. The all process could be divided into four steps:

Step 1 L-system Example

The recursive nature of the L-system rules lead to self-similarity and thereby, fractal-like forms are easy to describe with an L-system. Plant models and natural-looking organic forms are easily defined by increasing the recursion level so the form slowly 'grows' and becomes more complex. ^[10] Generally, there are three types of L-system model, and some have potential to be used on architecture, but not the others. In the following phase, the basic scripting will be shown to demonstrate that basic L-system is not a challenging algorithm for architects. Meantime, one of the type will be chosen to be an architectural structure system for the following steps.

Type 1: Space-filling curves

Type 2: Tilings

Type 3: Trees or plants

Step 2 L-system Case Study

L-system could work as an architectural tool for designing hierarchical, branching structure system. In this research, three projects of branching structure will be proposed to discuss. Unfortunately, there are only few projects insist their branching structure design based on the L-system. In the next chapter, the branching structure of L-system and non-L-system will be compared.

Project 1: L-system

The Tote / Serie Architects / Mumbai / 2009

Project 2: non-L-system

Stuttgart Airport Terminal / Von Gerkan, Marg+Partner / Stuttgart / 1991

Step 3 L-system Prototype of Branching Structure

A prototype is an early sample, model, or release of a product built to test a concept or process or to act as a thing to be replicated or learned from. A prototype is a schema that bring together information from all relevant possibilities into one general design model for a specific design situation. For the certain goal of this research, a serious of exploration through parametric design and Computer-aided design by Grasshopper constructs an executable model which need to be considered materiality, assembling and details.

Step 4 L-system Scripting and Modeling

Once a prototype has been decided, the next question would be how to replicate this element to become a real structure system, not just a tree-like sculpture. By parametric design, elements can be welded to each other very well, and it could be seen as “numbers of trees could make a forest”. However, due to the site of variety, “the forest” still needs to adjust according to several environmental, contextual factors or realistic restrictions, such as property line, height limit, actives, temperature, acoustics ... etc. In this phase, many plugins of Grasshopper will act as the most important role for solving foregoing problems then achieving morphing.

2. CASE STUDY AND METHODOLOGY

2.1 Mathematical Model by L-system

The central concept of L-systems is rewriting. In general, rewriting is a technique for defining complex objects by successively replacing parts of a simple initial object using a set of rewriting rules or productions. ^[11] The following alphabet illustrates the basic function of symbols, and these are general commands for creating patterns or models.

L-System Symbols ^[12]

G	move forward one unit with the pin down
F	move forward one unit with the pin up
+	yaw the turtle right by angle degrees
-	yaw the turtle left by angle degrees
&	pitch the turtle down by angle degrees
^	pitch the turtle up by angle degrees
/	roll the turtle to the right by angle degrees
*	roll the turtle to the left by angle degrees
%	change direction 180 degrees
!	increment the width of the next lines
~	decrement the width of the next lines
[save in stack current state info
]	recover from stack state info
{	start filled in polygon
}	end filled in polygon

Type 1: Space-filling curves (Hilbert curve)

In mathematical pattern, a space-filling curve is a curve which makes a one-dimensional interval into a two-dimensional area. There are many famous patterns in this category such as Hilbert curve, Peano's curves, Dekking's church, Kolams...etc. The following figure illustrates how Hilbert curve grow in each iteration. However, this curve not only could be a two-dimensional pattern, but could be three-dimensional model which still consist of only one curve.

Axiom: A

Angle: 90°

Rules:

$A = -BF + AFA + FB -$

$B = +AF - BFB - FA +$

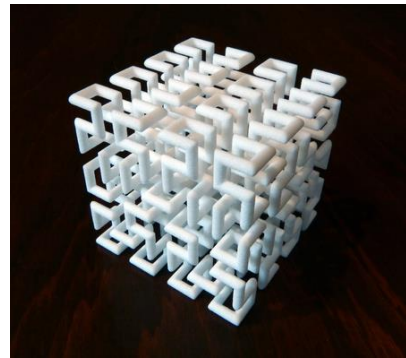


Figure 2.1 - Hilbert Curve (3-D Model)

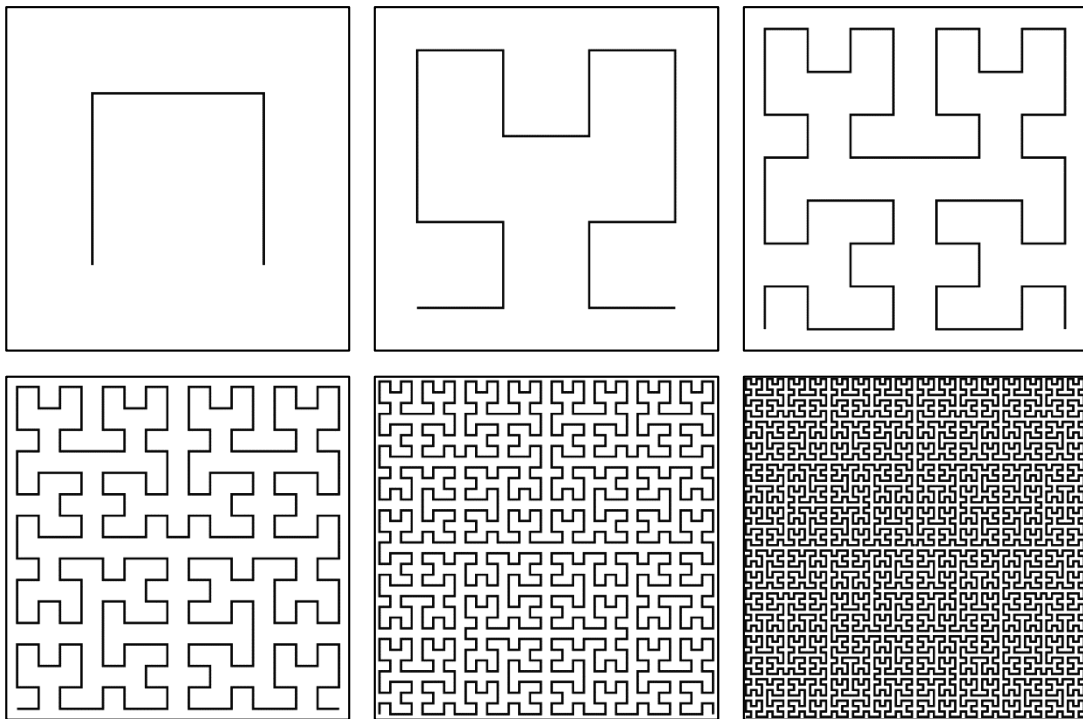


Figure 2.2 Hilbert Curve (2-D Pattern)

Type 2: Tilings (Penrose tiling)

Tiling is another usual pattern in L-system. The basic way to construct a tiling which could be rewritten by an L-system rule is dissecting a figure into smaller copies of itself. Penrose tiling and Sphinx tiling are most representative examples in this category. The tiling pattern has good potential to apply on certain two-dimensional surface or mesh, but it is still hard to interpret into a three-dimensional model.

Axiom: $[C]++[C]++[C]++[C]++[C]$

Angle: 36°

Rules:

$A = CF++DF----BF[-CF----AF]++$

$B = +CF--DF[---AF--BF]+$

$C = -AF++BF+++CF++DF]-$

$D = --CF++++AF[+DF++++BF]--BF$

$F =$

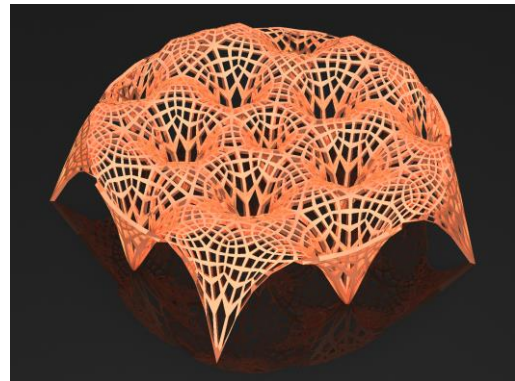


Figure 2.3 - Penrose tiling on stretched surface

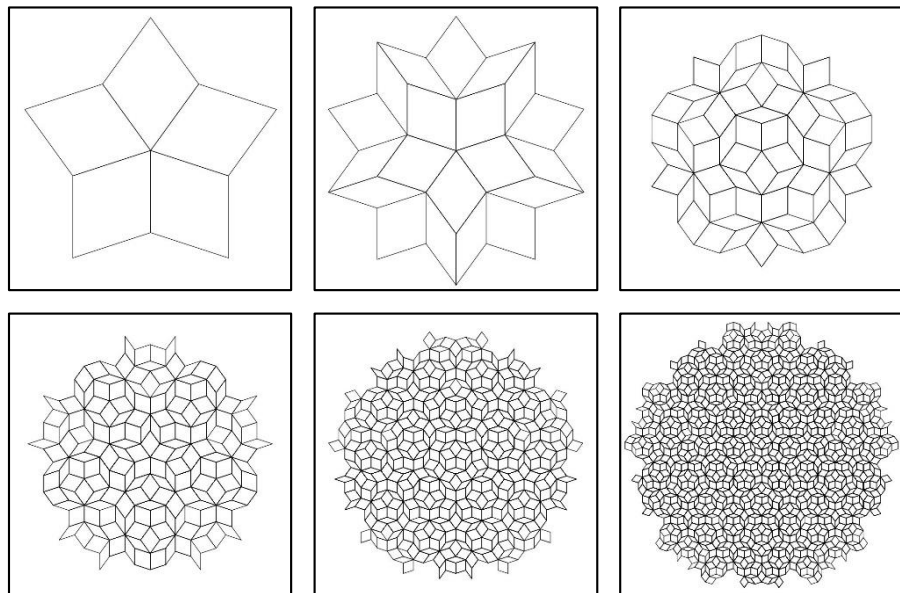


Figure 2.4 - Penrose Tiling

Type 3: Fractal-like branches

The tree-like pattern is the most common pattern to simulate how plants grow through L-system. The basic concept of an L-system is drawing a figure using a rule and repeat this rule in each part of the figure again and again. In this case, each part of the branches will divide into two or more sub-branches.

Axiom: FA

Angle: 30 °, 60 °, 90 °

Rules:

$A = B[-B]B[+B][B]$

$B = FA$

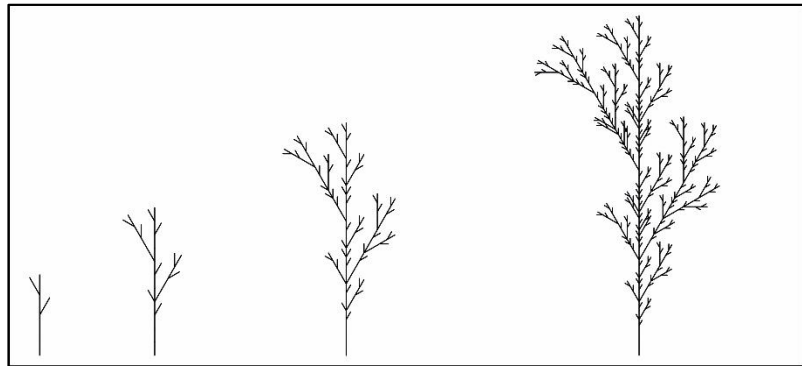


Figure 2.5 – Algae (Angle: 30 °)

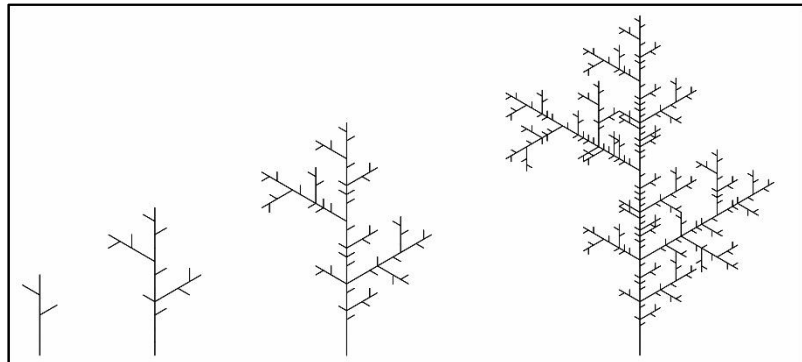


Figure 2.6 – Algae (Angle: 60 °)

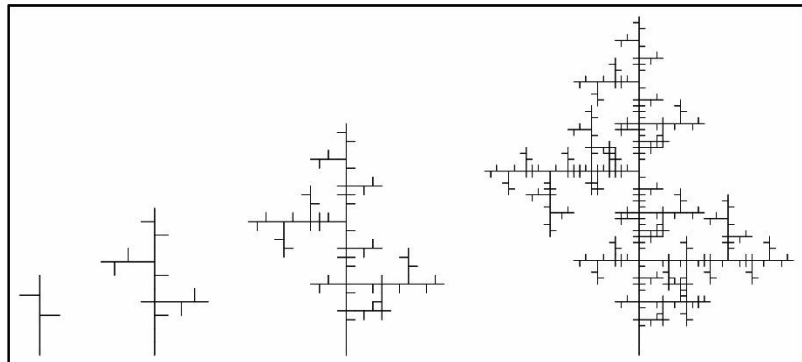


Figure 2.7 – Algae (Angle: 90 °)

In brief, space-filling curves creates a certain pattern with a non-breaking, continuous curve; Tilings are composed of variable, basic geometries; Tree-like L-system represents the fundamental structure of plants. Therefore, “trees” would have the most potential as the prototype of an architectural structure due to the following reasons:

(1) The plants themselves are good structural models in nature. The evolutionary process has found the efficient structural solution for the plants so that they could survive in the world for billion years.

(2) Unlike space-filling curves or Tilings could only generate linear form or two-dimensional geometries, tree-like L-system is able to be a three-dimensional framework.

(3) Many free online resources could be easily downloaded and used for simulating and visualizing variable plant models immediately.

For example, L-studio is a specific program for L-system to preview simulation models and performing virtual experiments which has been developed by University of Calgary. ^[13] Another choice of virtualization tool for architects would be a plugin for Rhinoceros and Grasshopper which called Rabbit. ^[14] The advantage for Rabbit is the plugin is cooperated with Grasshopper, so the architect can adjust the L-System rules in parametric environment and see how different L-System models affect their design works.

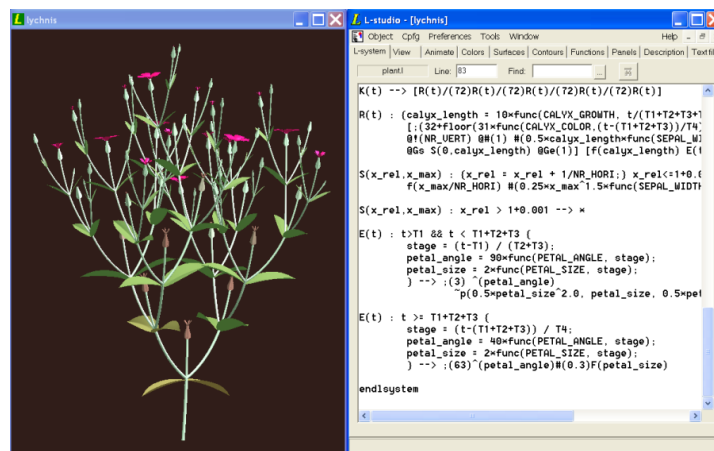


Figure 2.8 – The Interface of L-Studio

2.2 Architecture Application of L-system

Project 1: L-system

The Tote / Serie Architects / Mumbai / 2009

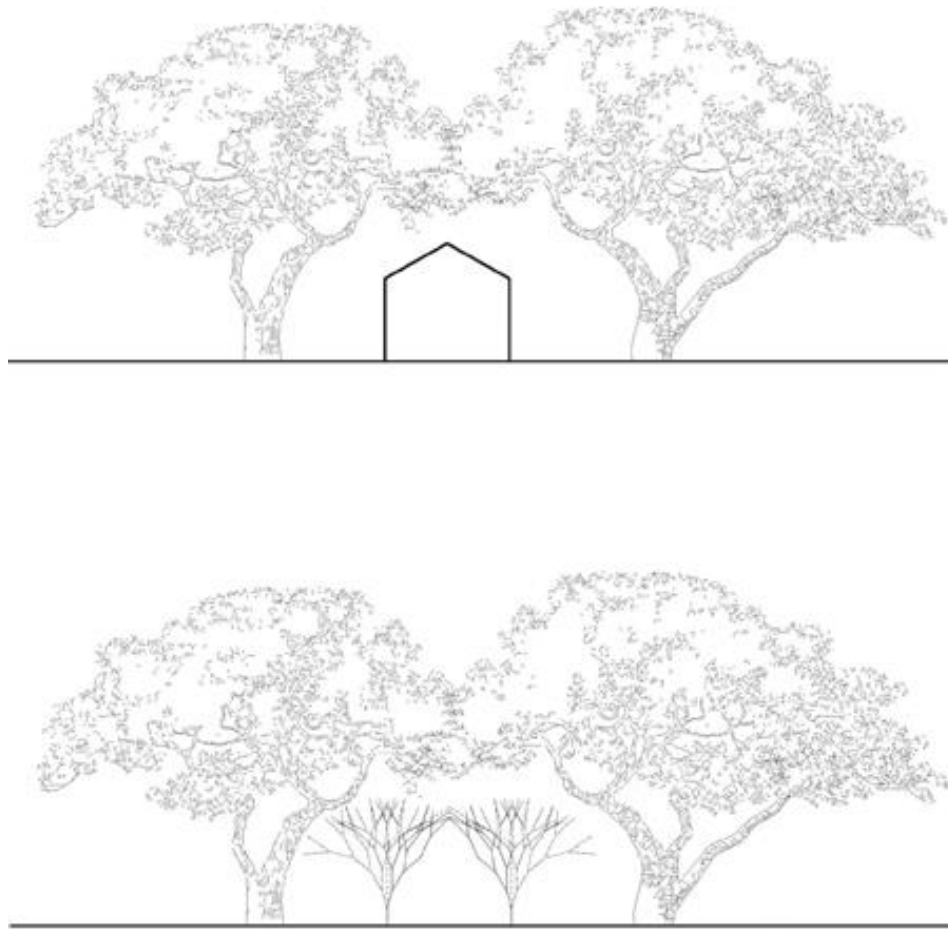


Figure 2.1 - The Tote Section Diagram

This project was an old building that was built in colonial period which, clients would like to convert it into a restaurant. However, the conservation guidelines called for the preservation and conservation of most areas of the roof. The architect attempted to extend the natural-like branch structure in the old building as the support for existing roof, so the new structure is proposed within the old building envelope.



Figure 2.9 - a tree column in The Tote



Figure 2.10 - The dining space in The Tote

The choice of the I-section was based on the fact that the web could be laser cut to ensure dimensional precision, while relying on the skilled fabricators to weld the flanges on and assemble the truss accurately. The truss geometry was altered for smooth branching as opposed to an angular one to reduce the number of weld joints. The success of the installation is that the final product conceals the fabrication method and appears to be a system of curved sections. [15]

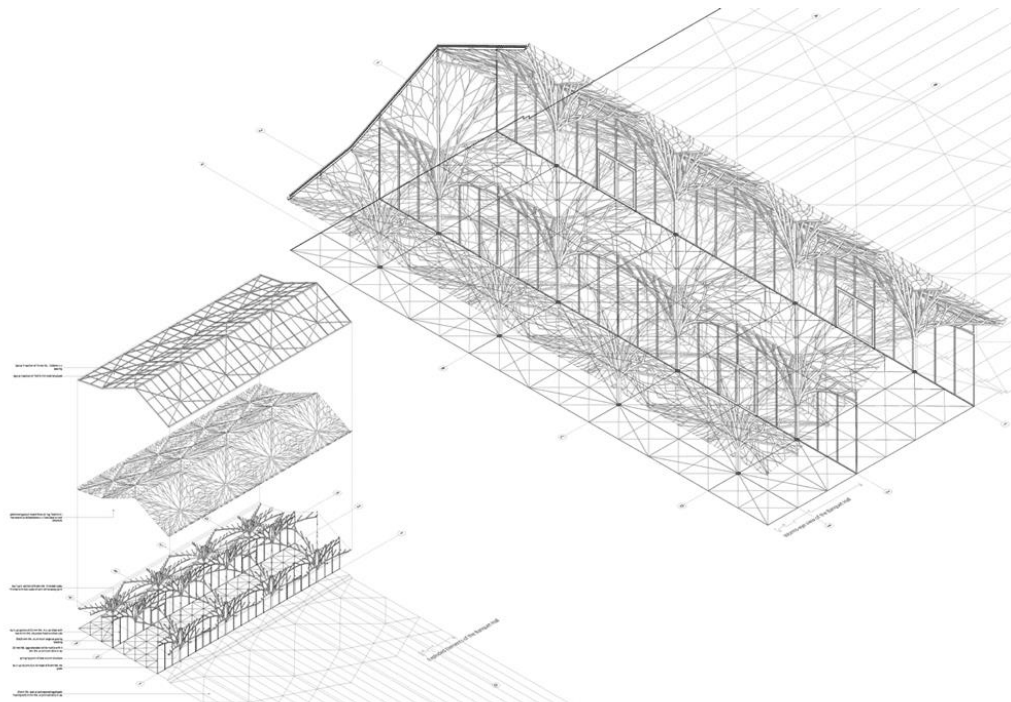


Figure 2.11 – Structural Diagram of The Tote

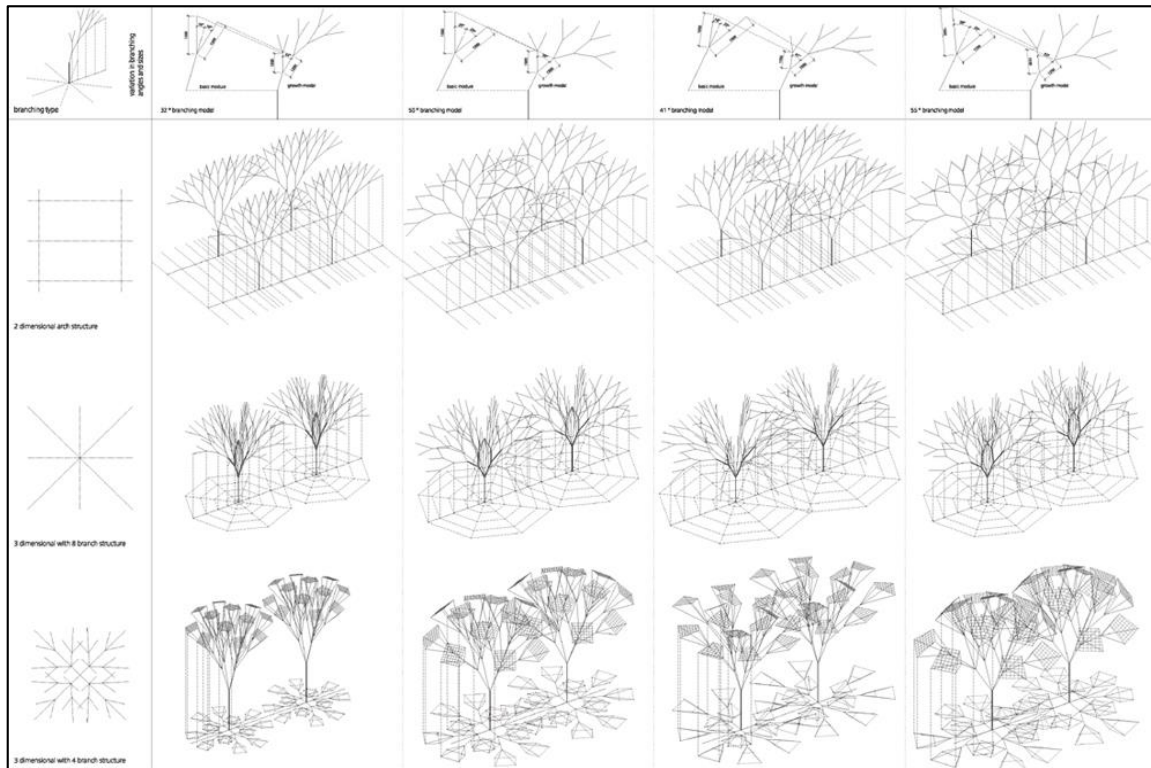


Figure 2.12 – L-System Analysis of The Tote

In this case, designers work on the grid system that is existed on the roof and study how different branch angles connect to the roof. However, if the given site or the existing building is not a regular shape as The Tote, this crafted structure might not be able to be constructed due to their materials and the details of the joints they chose.

Project 2: non-L-system

Stuttgart Airport Terminal / Von Gerkan, Marg+Partner / Stuttgart / 1991



Figure 2.13 - The Columns of Stuttgart Airport Terminal

Stuttgart airport terminal looks very similar to L-System, but it is not. There is a slight difference between this project and L-System. In this project, the structural engineer and architect explore branching structures by “Genetic algorithms” (GAs) for minimal paths. The similar method could be found in Antoni Gaudí’s design. While designing the Sagrada Família and Church of Colònia Güell, in order to evolve a structure in equilibrium, He designed catenary cord models. These methods are ways they set up the top spots for the columns, then find the best path to meet the ground. In other words, these structures grow from the top down. In contrast, L-System actually is a bottom-up process.

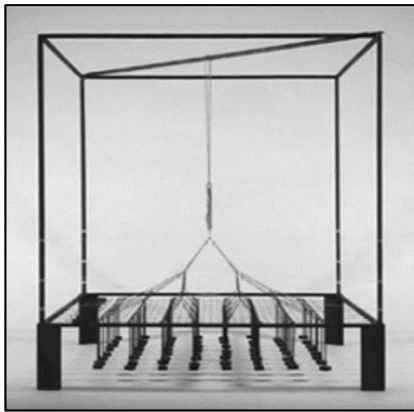


Figure 2.14 - hanging models of branching systems

Figure 2.15 - Antoni Gaudí’s catenary cord models

2.3 L-system for Structure

In the design process, the prototype of tree unit has been decided and then duplicated because L-system can create only one tree per run. In this circumstance, a simple branch string will be chosen for demonstration. The simplest geometry would be triangle or rectangle so that the plan can easily organized for the next step. Thus, branch with three twigs and four twigs are the better prototypes for the structural system in this case.

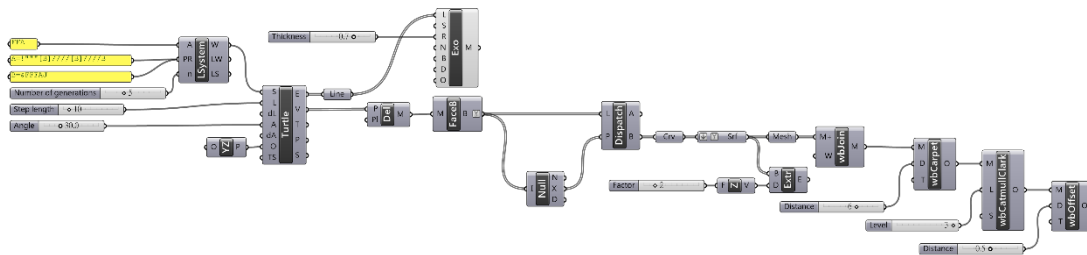


Figure 2.16 - The script of L-system in Grasshopper / Rabbit

Axiom: FFA

Angles: 22.5 °

Rules:

A = !" [B]////[B]//// [B]////B

B = &FFFAJ

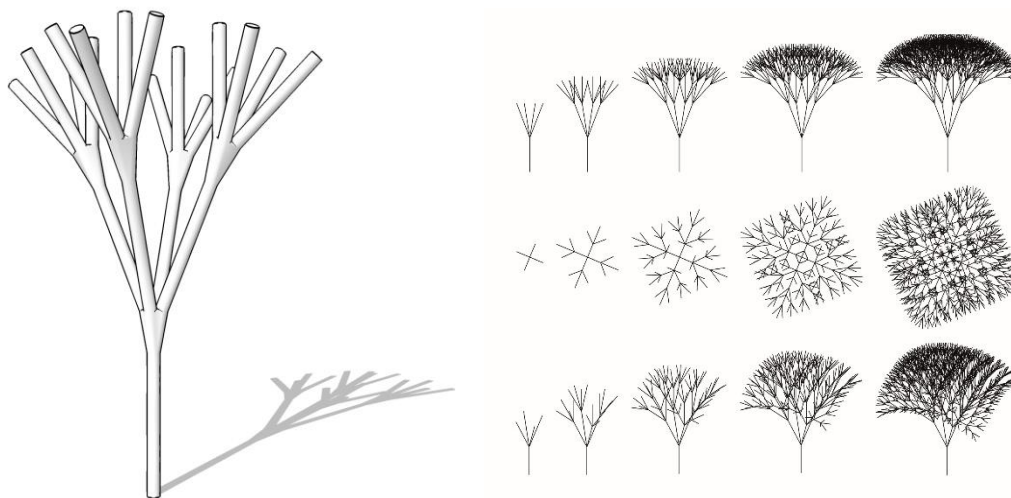


Figure 2.17 – Branch with 4 twigs

Axiom: FFA

Angles: 30 °

Rules:

A = !"[B]////[B]////B

B = &FFFAJ

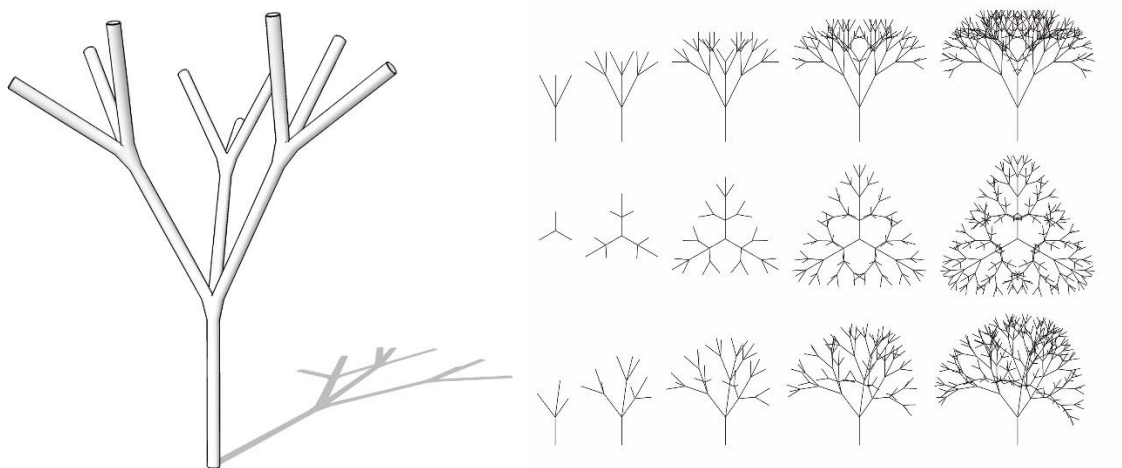


Figure 2.18 – Branch with 3 twigs

For the reasons of avoiding over complication, the second iteration of branch with 3 twigs will be chosen as the prototype for the demonstration on the site.



Figure 2.19 – Early stage of work flow

Architects as programmers, they have to select the potential prototype in early stage. Once they get the results through parametric tools (Grasshopper), they can change the prototype or complicitity for more testing.

2.4 Tool and Algorithms

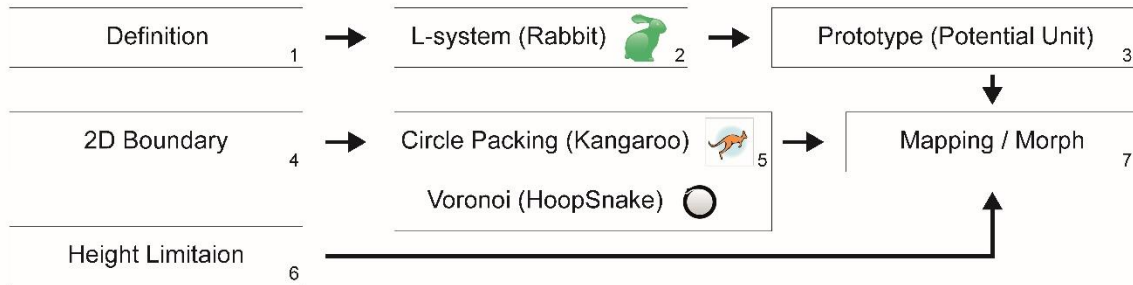


Figure 2.20 – Main work flow

After the prototype has been created, the next question would be how each tree structure can be organized together on the site. The answer is that, the site should be subdivided into several small pieces for the trees. Here are two ways one could divide the area into triangles approximately equally.

Method 1: Circle Packing

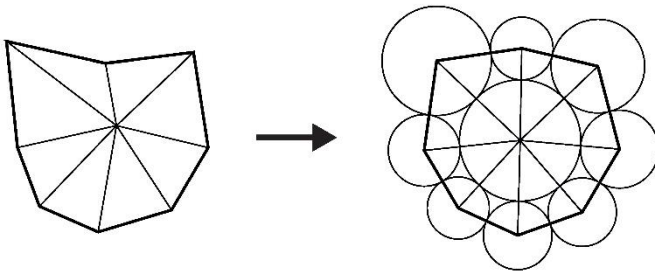


Figure 2.21 – Circle Packing

Method 2: Voronoi and Delaunay

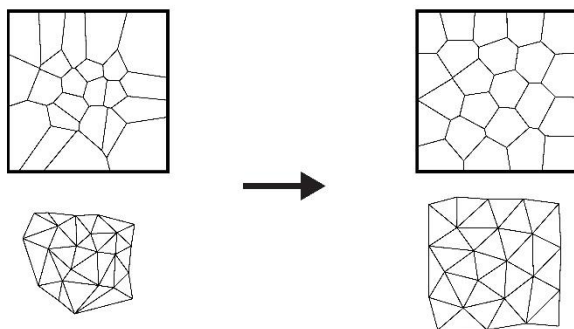


Figure 2.22 – Voronoi and Delaunay

Circle packing can adjust the triangular meshes through circles, however, it also changed the original boundary. Thus, this division cannot always fit into the area that designer desired. In contrast, Voronoi can control the boundary much better, but it still needs a rectangular boundary at the beginning and then crop the redundant area after computation. Nevertheless, Voronoi is still a simple way to get the equally triangles from irregular area.

After the triangles have been finished, the height of the trees would be the last parameter for adjusting trees. If each tree could be seen as a triangular prism, the prism will be able to transform to any different height, size or angle.

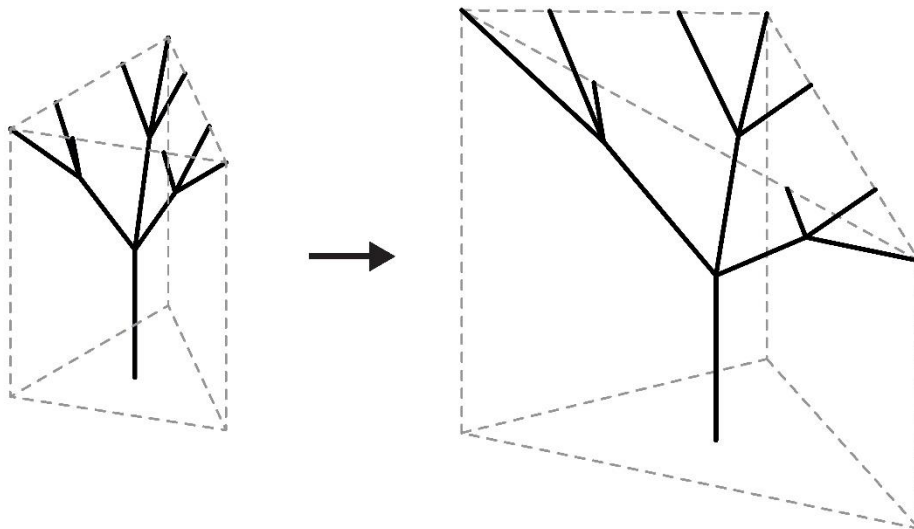


Figure 2.23 – Mapping and Morph

3. DESIGN AND IMPLEMENTATION

3.1 Site and Program

MoMA PS1 is one of the oldest and largest nonprofit contemporary art institutions in the United States. It is located in the Long Island City neighborhood of Queens in New York City, New York. An exhibition space rather than a collecting institution, MoMA PS1 devotes its energy and resources to displaying the most “experimental” art in the world.



Figure 3.1 – MoMA PS1

A catalyst and an advocate for new ideas, discourses, and trends in contemporary art, MoMA PS1 actively pursues emerging artists, new genres, and adventurous new work by recognized artists in an effort to support innovation in contemporary art. MoMA PS1 achieves this mission by presenting its diverse program to a broad audience in a unique and welcoming environment in which visitors can discover and explore the work of contemporary artists.^[16] They present over 50 exhibitions each year, including artist retrospectives, site-specific installations, historical surveys, arts from across the United States and the world, and a full schedule of music and performance programming.



Figure 3.2 – Warm Up 2014

Moreover, an annual competition hosted by MoMA PS1 and The Museum of Modern Art that invites young architects to submit design proposals for MoMA PS1's courtyard is called "The Young Architects Program". The winning entry is converted from concept to construction and becomes the architectural setting for MoMA PS1's summer "Warm Up" music series. Warm Up was conceived in 1997 as a summer-long dance party to attract crowds to MoMA PS1 and Long Island City, Queens. The series runs every Saturday from July through early September and draws thousands of local and international visitors each day. ^[17]

This program is committed to offer emerging architectural talent the opportunity to design and present innovative projects, challenging each year's winners to develop creative designs for a temporary installation at the courtyard that provides shade, seating, and water. The architects must also work within guidelines that address environmental issues, including sustainability and recycling. The objective of this project is to provide visitors with an outdoor recreational area for the summer and make the best use of the pre-existing space and available materials. The architects follow a program with a tight budget, and are involved in every aspect of the design, development, and construction of the project.

In other words, according to foregoing requirement, principal or statement, the characteristic of design they are looking for could be summarized into following points:

1. An experimental approach
2. A temporary installation (easy to construct and demolish)
3. An outdoor pavilion with seating in the courtyard
4. Sustainability and recycling
5. Friendly in urban context

The specific design goal of my thesis design would be to study how parametric design technologies can redefine and support the process of bionic façade. The Young Architects Program is a wonderful opportunity to practice and achieve this idea. Through the parametric tools, the canopy at the courtyard could be precisely simulated in the model with any weather conditions, such as sun shade or wind tunnel, for green issue. In addition, the model would be constantly optimized by the program and fabricate a mock-up to evaluate its feasibility for considering whether the installation is easy to construct or demolish.

As a client in this thesis design, MoMA PS1 would be very potential reasonable. The eager of contemporary art would be the best reason for the experimental project exist in this laboratory (courtyard).



Figure 3.3 –The 2004 Winner of The Young Architects Program: nARCHITECTS

3.2 Site Analysis

Site: MOMA PS1 (20,500 sqft courtyard), 22-25 Jackson Ave, Long Island City, NY

Housed in a distinctive Romanesque Revival building (a former public school), PS1 mounts cutting-edge shows and hosts an acclaimed international studio program. Artwork crops up in every corner, from the stairwells to the roof. PS1 became an affiliate of MoMA in 1999, and sometimes stages collaborative exhibitions. Reflecting the museum's global outlook, it has focused in recent years on such luminaries as Janet Cardiff and Olafur Eliasson. It also hosts a summer's popular Saturday-afternoon party.

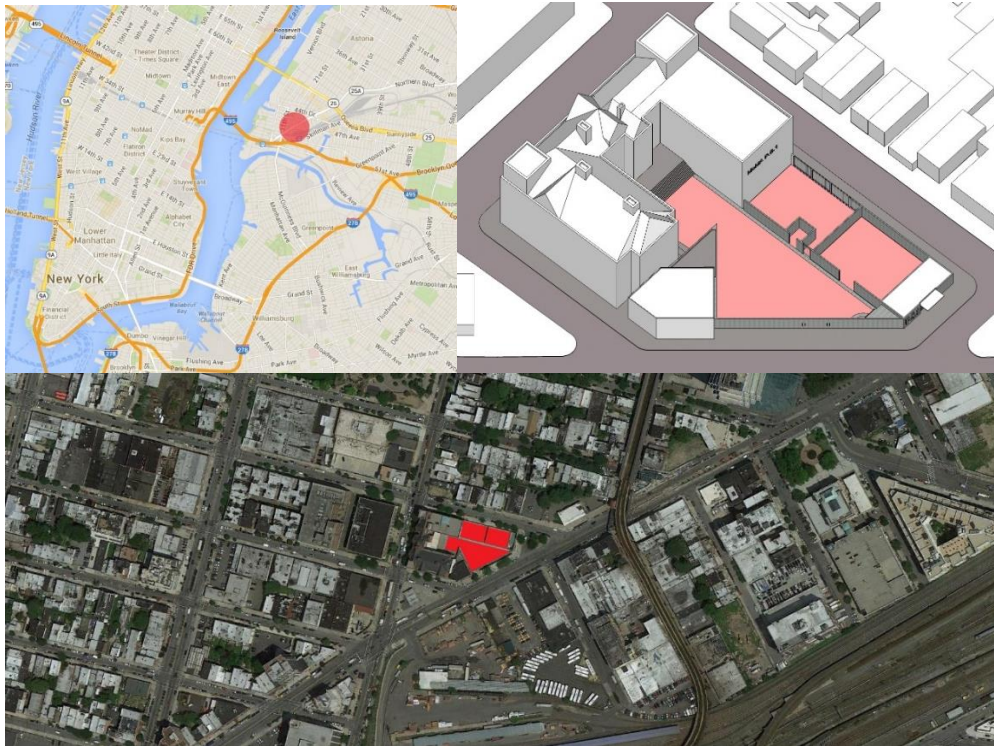


Figure 3.4 – MoMA PS1 in New York City

Figure 3.5 – Site Model

Figure 3.6 – MoMA PS1 aerial view

The red zone is the courtyard area of MoMA PS1 which is surrounded by a series of enclosing wall and old buildings. Roughly, the wall divides the courtyard into three pieces. The main entrance to access the museum is on the east corner of the block.

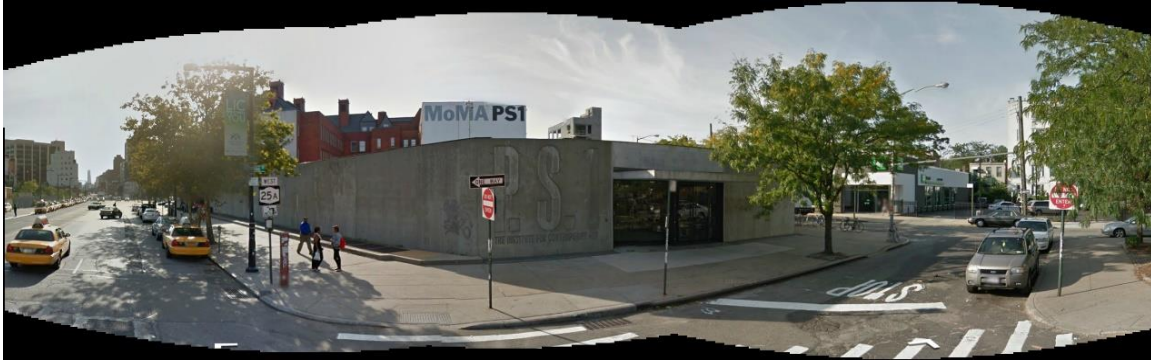


Figure 3.7 – The street view of main entrance at the east corner

For MoMA PS1, Andrew Berman Architect has designed a building to be used for entry, ticketing orientation, and art display to be located in the first open courtyard of the museum complex. Visitors to the museum will enter in, and then pass through this building out into the main courtyard of MoMA PS1 on their way to the galleries. The construction is of “cast concrete”. Doors are assembled of hot rolled steel and glazed with surface applied laminated glass sheets.



Figure 3.8 – The view from courtyard to exit



Figure 3.9 –The view on the street and in the courtyard

The building that houses MoMA PS1 was built in 1885 as Long Island City’s Public School, and has been incrementally renovated over time to become a preeminent art space by Andrew Berman Architect as well.

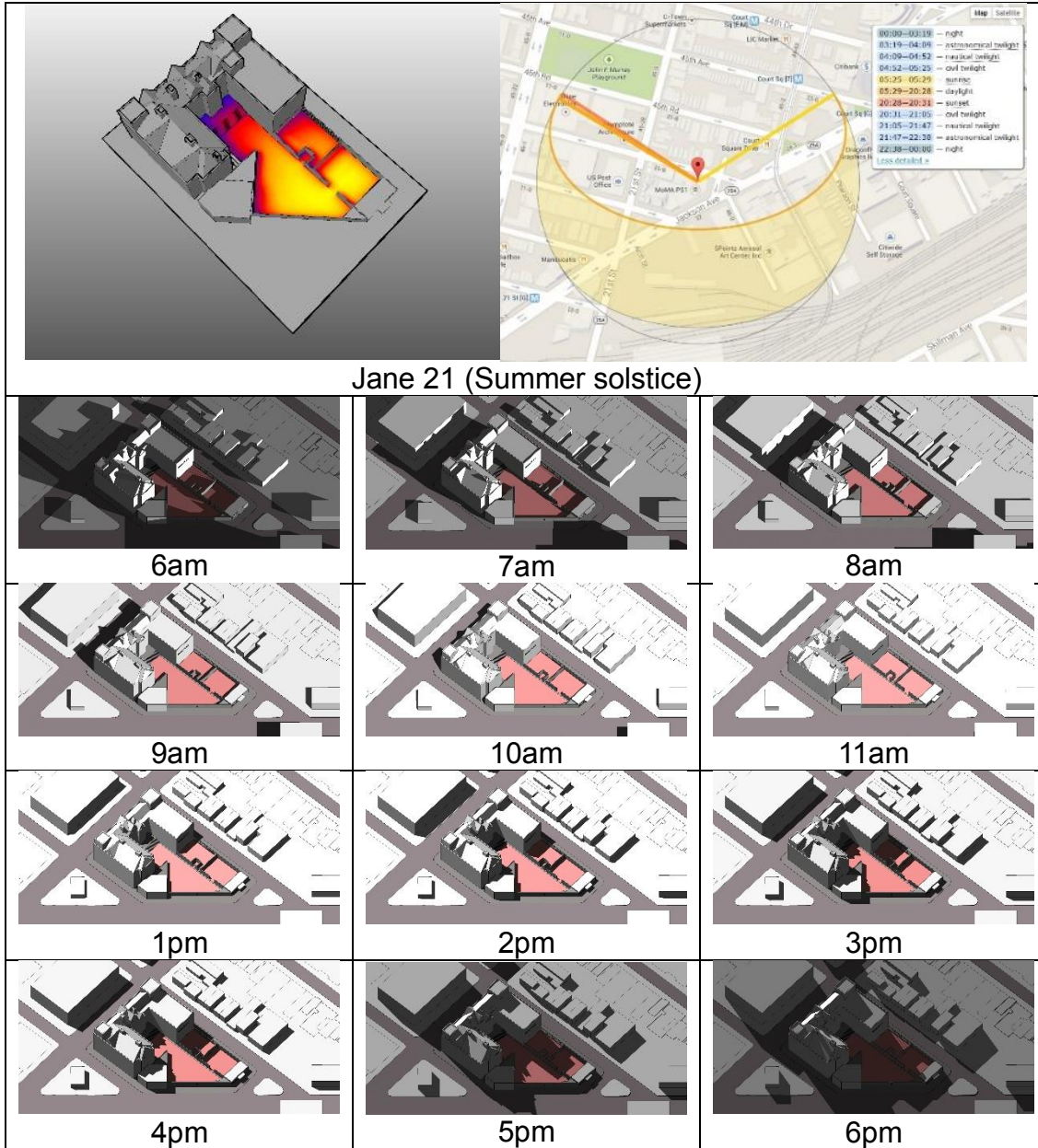


Figure 3.10 – The view on the street and in the courtyard

MoMA PS1 presents “Warm Up” music series every year, beginning around June and taking place every Saturday this summer through September in this courtyard. The analysis indicates the shadow will cover the most area of the courtyard by main buildings in the afternoon. Moreover, buildings shade the entire courtyard earlier in September than in June at approximate 3pm. For this reason, the shadow would be a main factor which affects the quality of the design in this outdoor space because it provides an appropriate shelter has noted in the program.

3.3 Design and Implemented Process

As the diagram shows, the orange area is where trees could be built, and it is also an irregular geometry. However, this area could be subdivided by Voronoi Pattern to approximately equal pieces. And the strategy for the canopy's location will cover the hotter area in the courtyard according to the shadow and thermal analysis.

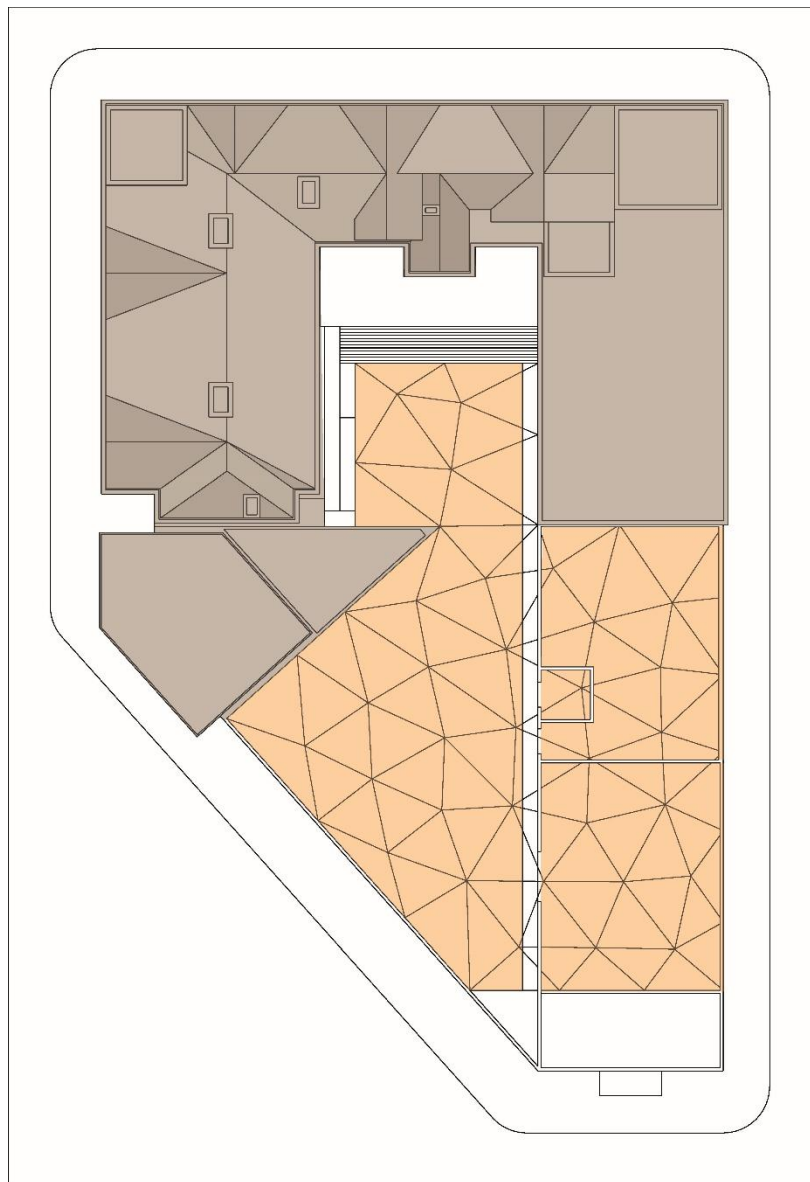


Figure 3.11 – Subdividing Courtyard

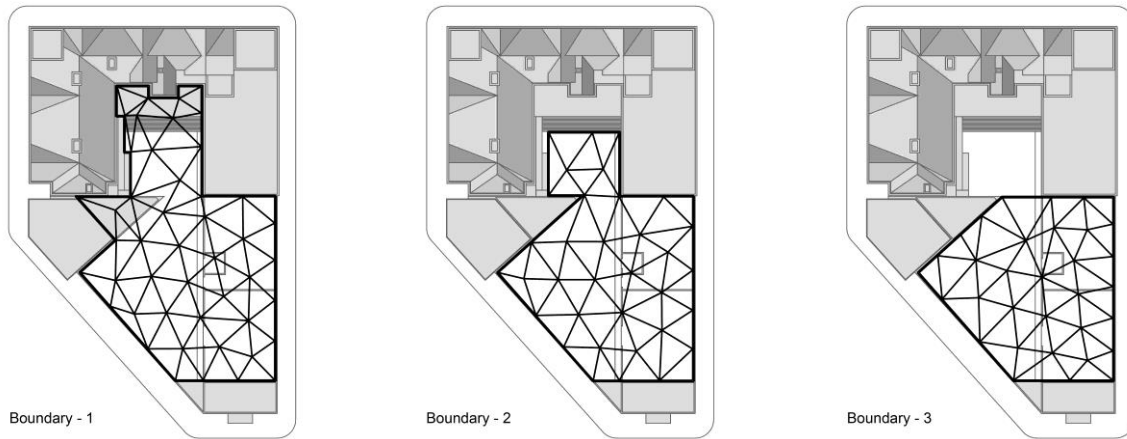


Figure 3.12 – Different Boundaries

In addition, even under the conditions of different boundary shapes, parametric design can quickly identify the reasonable division for them. Hence, via this program, architects can see the outcomes in a short time. Finally, this project chooses the pentagon of “Boundary-3” as a setting boundary, then subdivides and optimizes it into equally triangle which can be used to embed the L-system trees.



Figure 3.13 – Roof Plan

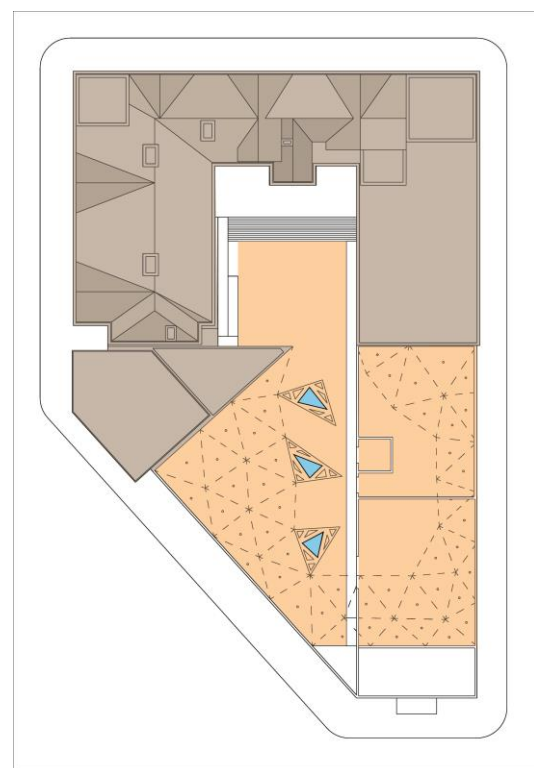


Figure 3.14 – Ground Plan
Some triangles are on the ground to be sitting and pools

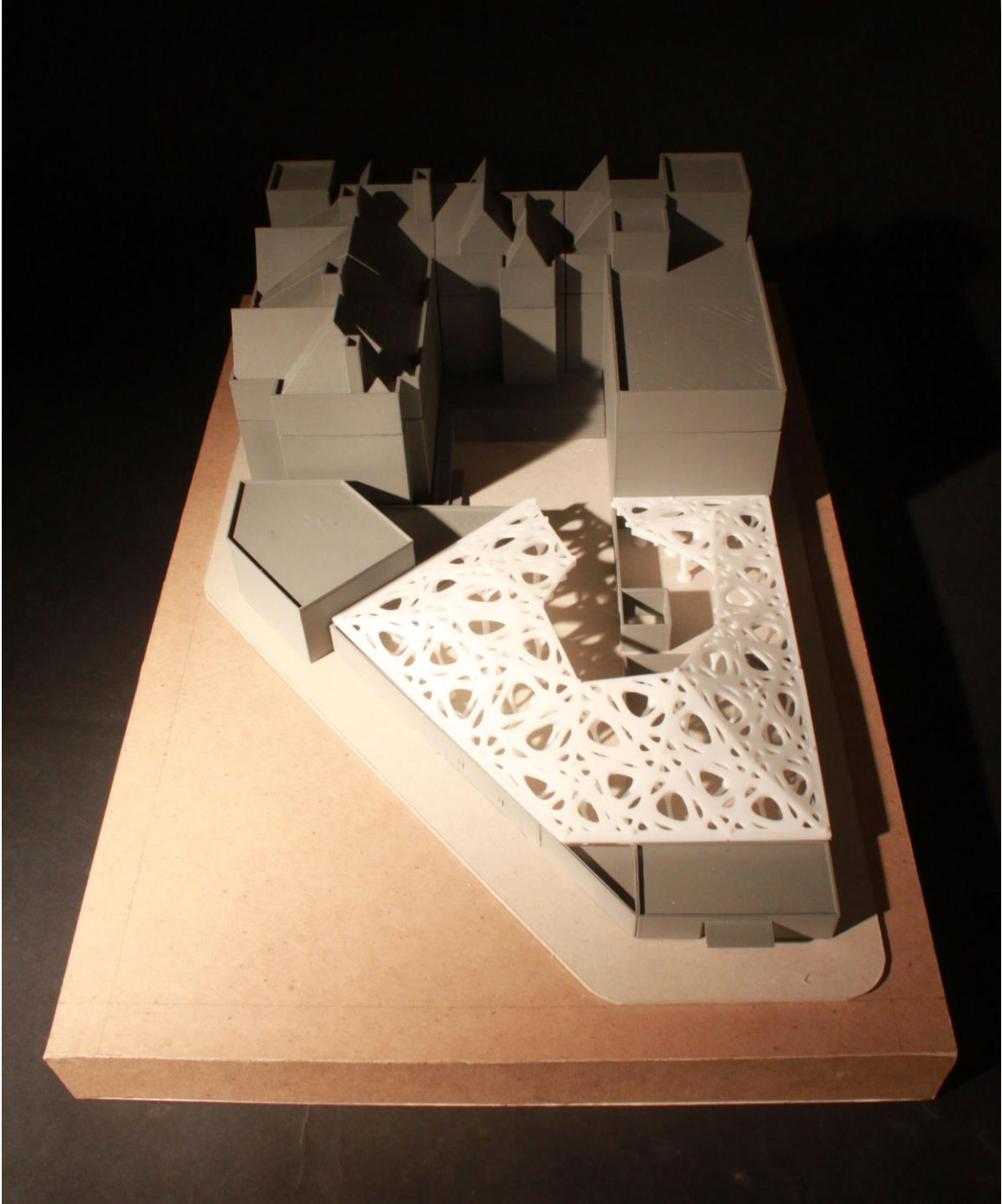


Figure 3.15 – Site Model

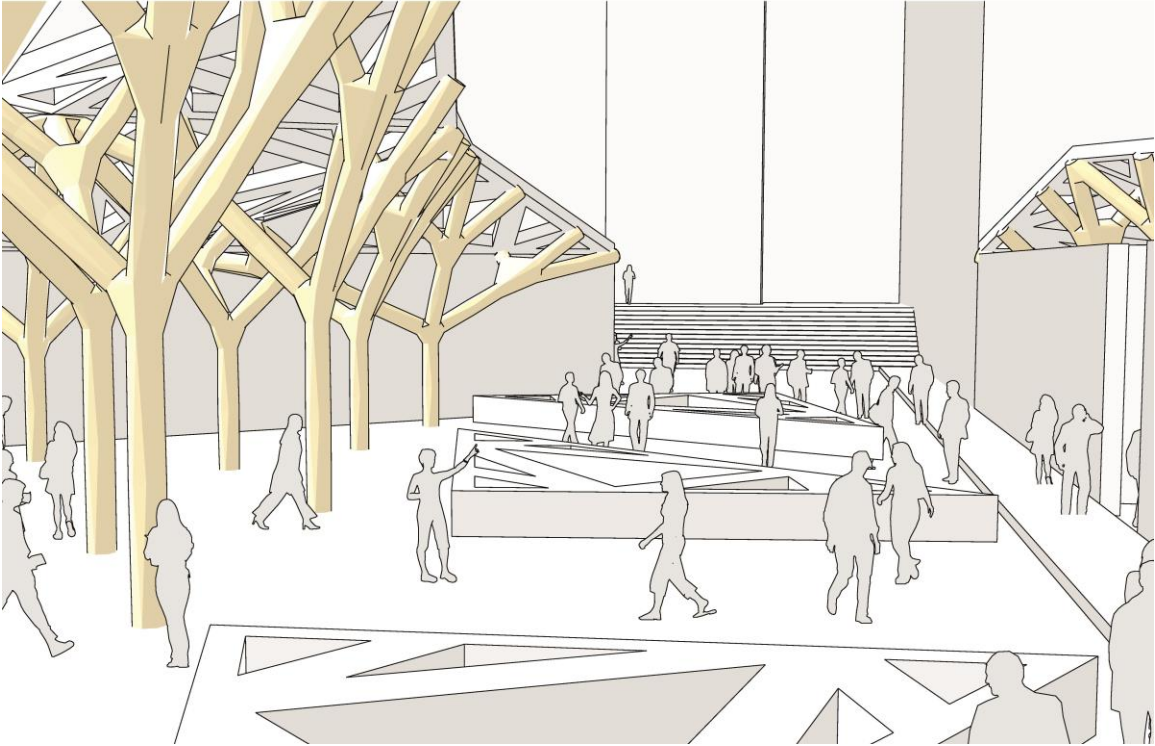


Figure 3.16 – Perspective 1

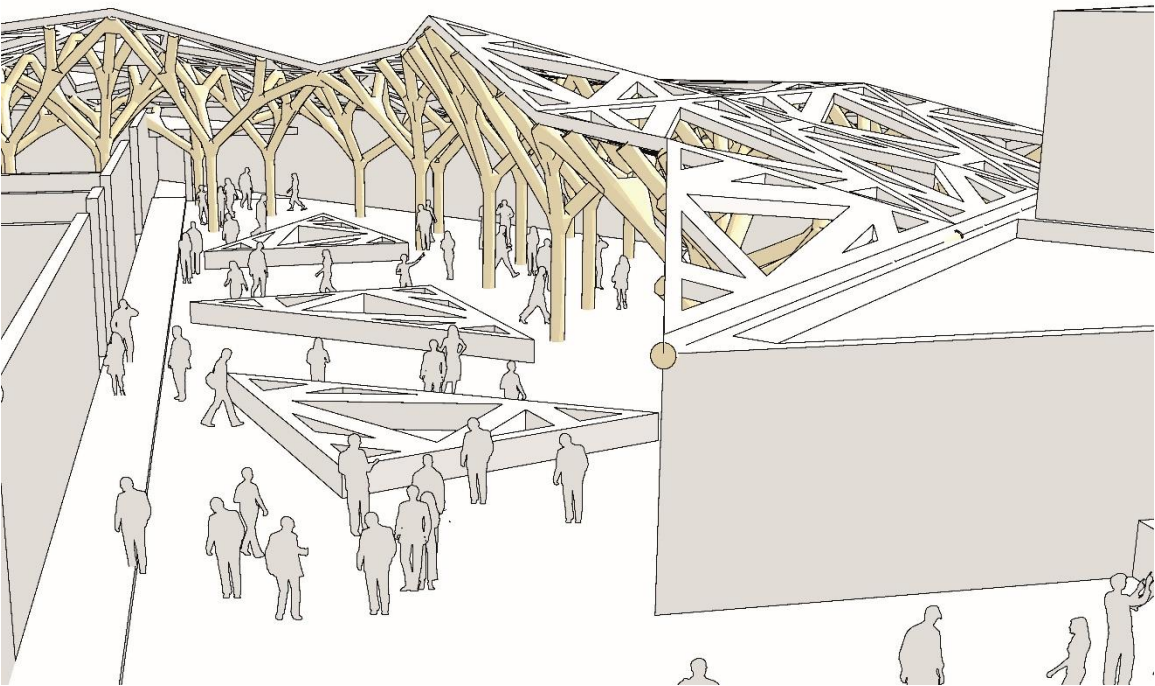


Figure 3.17 – Perspective 2

3.4 Detail and Material

Detail

In the 1950s, Austrian-born sculptor Erwin Hauer designed and built architectural screens and walls whose complex and intriguing geometry attracted much admiration at the time. It is based on carefully structured modules which allow for intricate and in some cases infinite patterns of repetition, sometimes used to create limitless, basically planar, screen-like formations, and sometimes employed to make more multidimensional structures. Based on new technology, we are able to use the parametric tools to make a skin or screen hold more flexibility and complexity.



Figure 3.18 – The screen by Erwin Hauer in Vassar College

Because the L-system structure might create any angles of the twigs at the joint, it will make some challenges on detail design and choice of material. According to MoMA PS1 required that sustainability and recycling should be considered in this project, the joint that can be mass produced and reused would be an important mission.

The following diagrams and models provide an idea for this significant joint. In this demonstration, the branches above the hinge can be rotated without limited angle. In addition, they can be speedily assembled and disassembled on the site. Furthermore, the hinges which were disassembled from one built shelter are reusable in building another new shelter.

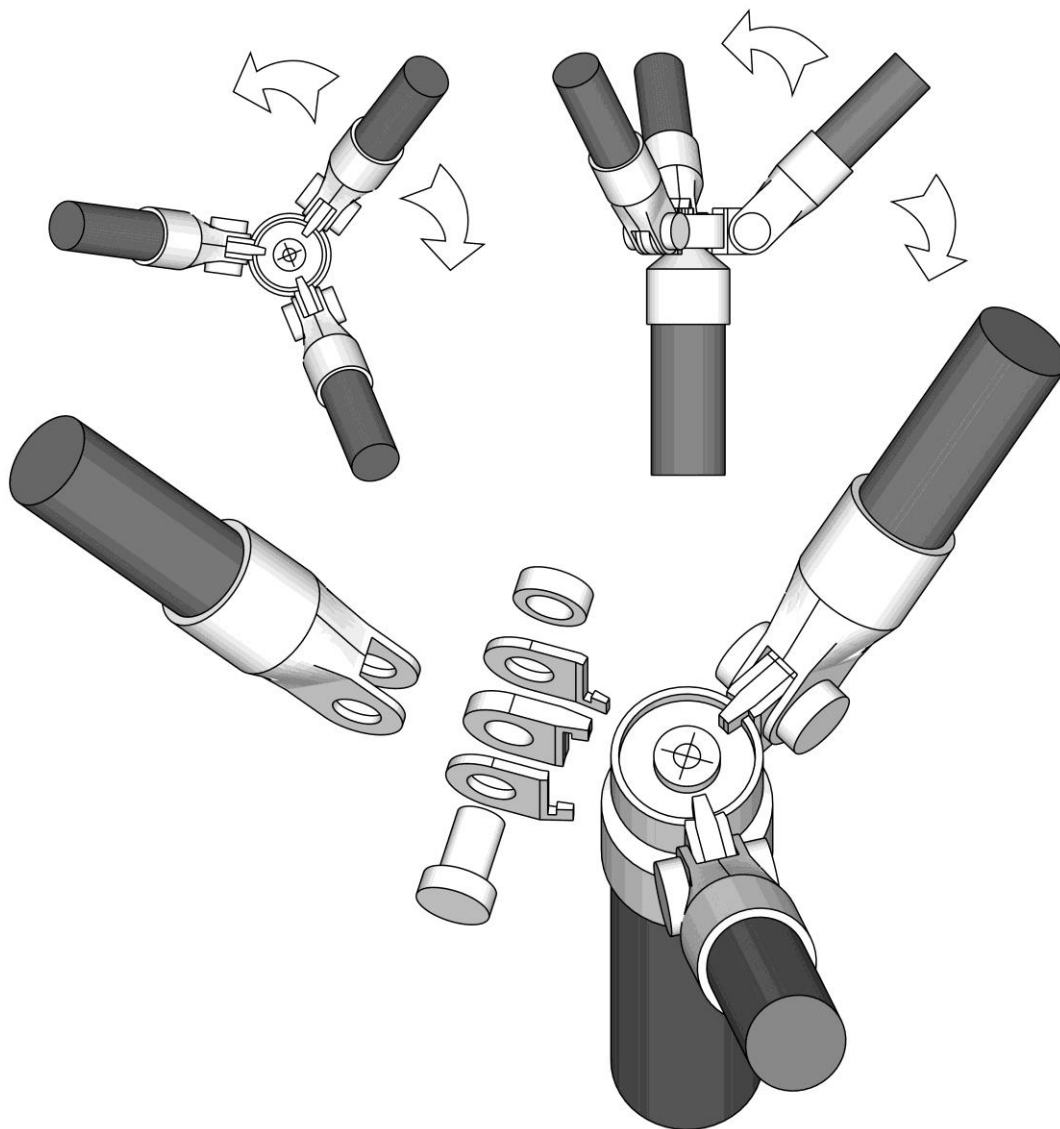


Figure 3.19 – The Detail of the Joint

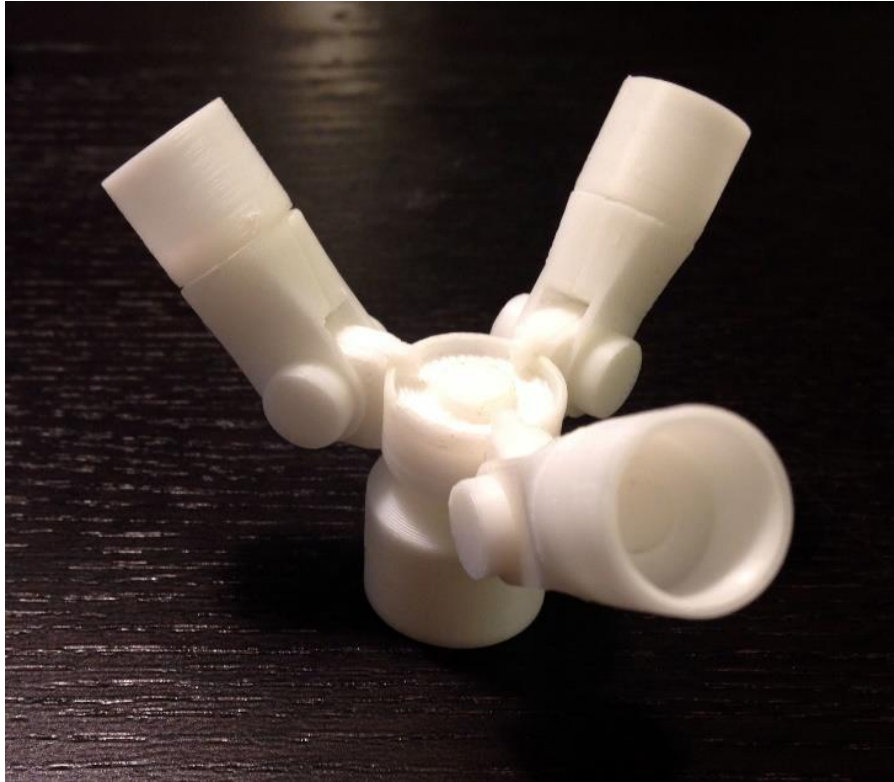


Figure 3.20 – The joint by 3D print

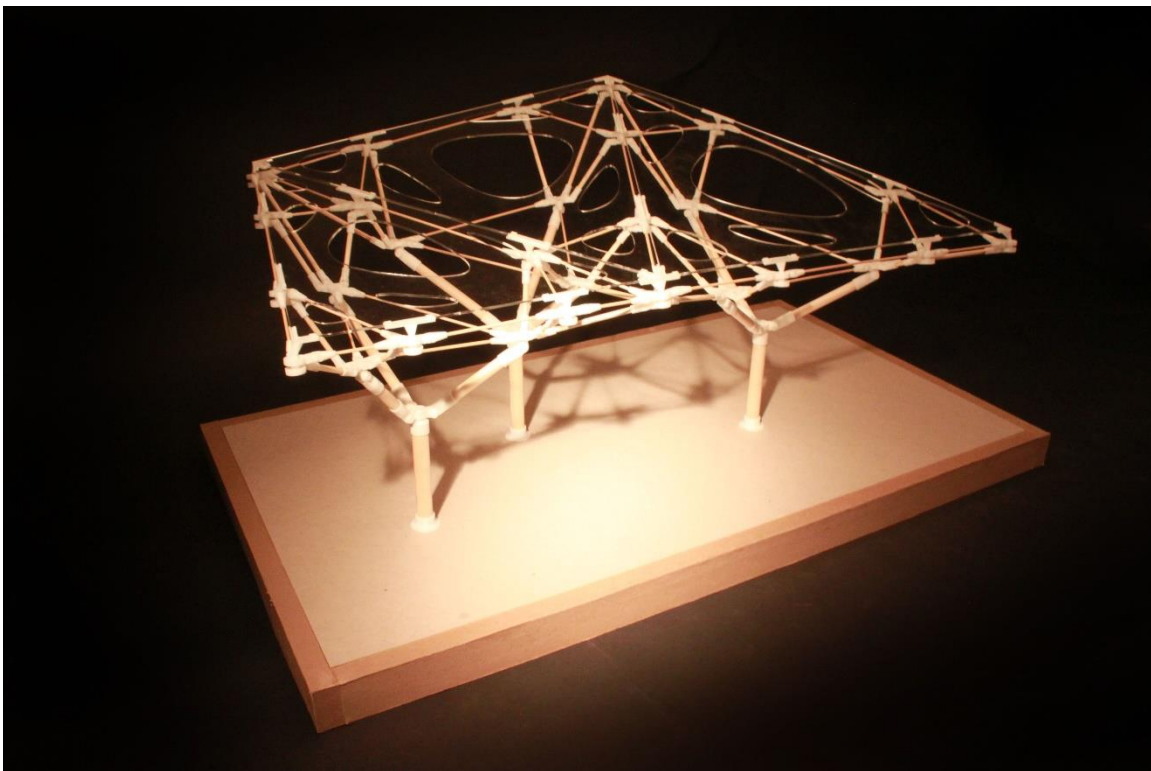


Figure 3.21 – Detail model

Material



Figure 3.22 – Scheme Production and Recycling

The certain plastic has used to build a curving pavilion in Stuttgart, Germany, which is made from a “bioplastic” containing over 90 percent renewable materials, thus would be a good choice to apply to this project. The pyramidal modules are made by extruding bioplastic granules into sheets before thermoforming them to create the faceted shapes and trimming off the excess material. In the meantime, the scrap would be recycled.



Figure 3.23 – ArboSkin pavilion by ITKE

Developed by project partner TECNARO within the framework of the research project ARBOBLEND, a special type of bioplastic granules was employed, which can be extruded into sheets and further processed as required: the sheets can be drilled, printed, laminated, laser cut, CNC-milled, or thermoformed to achieve different surface qualities and structures and eventually produce various molded components. The semi-finished products serve as cladding for flat or free-formed interior and exterior walls. The material can be recycled and meets the high durability and flammability standards for building materials. ^[18] Therefore, this bioplastic will be a considerable solution for the screen of the tree on the top.



Figure 3.24 –The water pool
by YAP 2013 Winner CODA

The screen or shelter would be lightweight temporary pavilion that maximizes its spatial performance while minimizes structure and material. The pavilion would be supposed to be an iconic gathering place for the music festival attendees. Located on an empty lot within the courtyard of MoMA PS1, the design emerged out of a desire to create a spatial vortex whereby visitors would feel drawn into the pavilion center and subsequently drawn back out into the larger festival site or surrounding buildings. In addition, fog nozzles spread a cool halo of mist which could be a good way to lower the temperature in the courtyard.

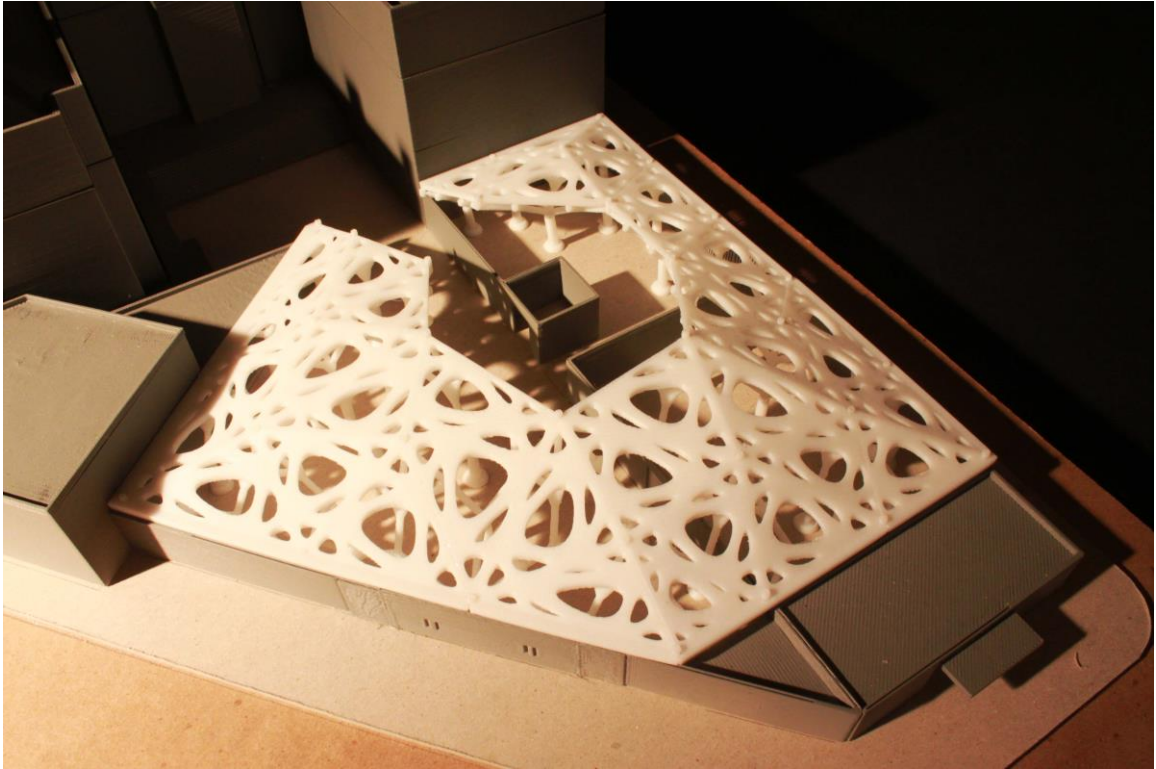


Figure 3.25 – The L-system structure in MoMA PS1 courtyard (physical model)



Figure 3.26 –The L-system structure in MoMA PS1 courtyard (3D rendering)

CONCLUSION

To sum up, L-system is an applicable tool for architect to study natural form or structure. Architects can easily experiment and visualize very unique and exciting array of shapes. A design can begin with a very simple set of rules. All experimental forms, variations and transformations could be previewed immediately in an axiom by rule writing.

However, the following restrictions are still problems when the pattern or form of L-system be used for architectural structure.

- (1) The basic concept of L-system is to generate a pattern using a rule and repeat this rule in each part of the pattern again and again. Once the iteration goes to higher value, the computer will run very slowly and even crash. Thus, overly complicated patterns or forms would not be suitable. It not only makes more difficulties on computing but also creates considerable challenges on construction sites.
- (2) This project chooses one type of the L-system, the fractal-like branches, as a prototype of an architectural structure to develop. L-system is a unidirectional growing system. It continually grows and splits toward a certain direction from a starting point and consistently repeats its rule. With the increase of iteration, the shape that is composed by the end points will be more and more complex, fragmental and organic. It would no longer be a simple geometric form. In other words, it will be more like a real tree.

In the nature, every tree is an individual structure. In general, the tip of branches from different trees would not be connected and function as a space frame system. In order to develop a stable space frame structure, the value of the iteration is limited. It is required to keep in a low value so

that the branch prototype can be simply connected. In other words, the joints between complicated trees which are generated by high iteration value will be hard to deal with. However, if the structure of the shelter is composed by a single tree rather than a number of trees, the value would not be limited so strictly. The only consideration will be whether the branch tip is too complicated to be built in real condition.

- (3) In addition, this project only uses the prototype of the branch with three twigs because this type of branch grows approximately in a triangular prism. Any irregular area can be subdivided by triangle so the branch with three twigs has better capability to adapt to complex site condition. However, if the prototype is the branch with five or seven twigs, the site area would be difficult to be fully subdivided by pentagon or heptagon.

Hence, the foregoing problems could be further issues for L-system research.

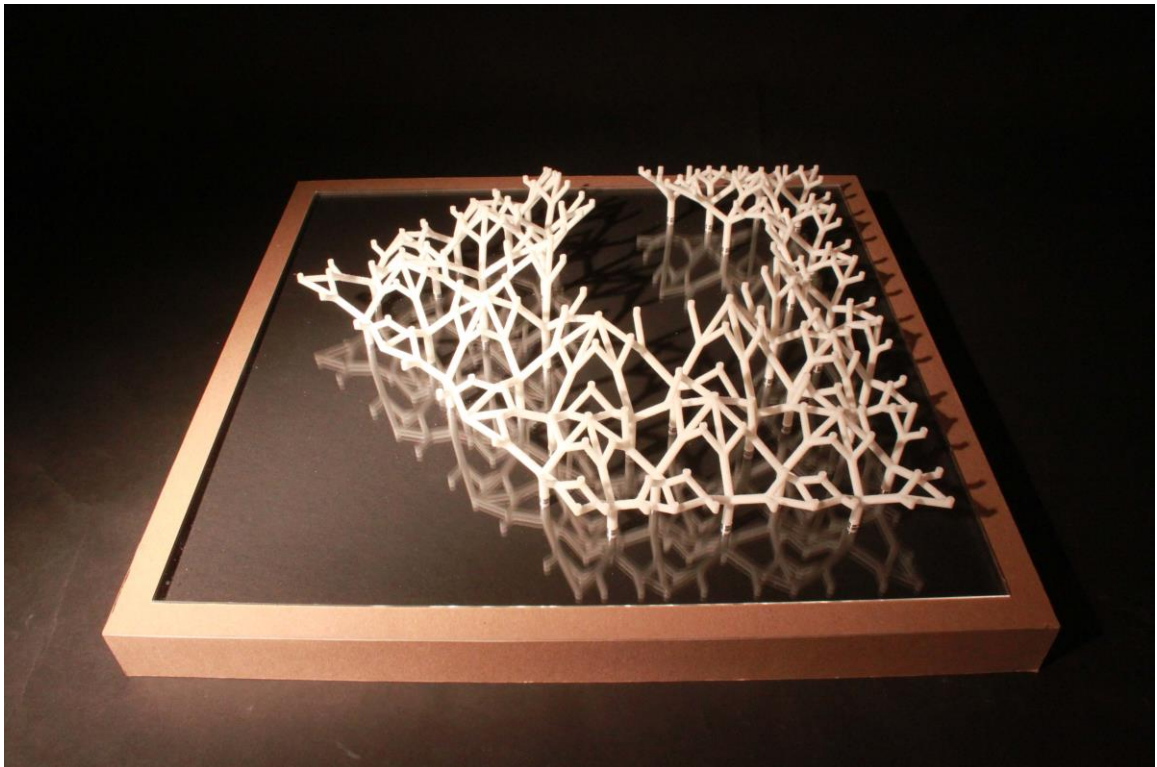


Figure 3.27 – The Connected Trees

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